THESIS

ON

STRENGTHENING OF CERTAIN IMPORTANT BRIDGES OF MAIN LINE

OF

BOMBAY, BARODA AND CENTRAL INDIA RAILWAY

PRESENTED BY

RICHARD MACLEAN, B.SC.

FOR THE DEGREE OF DOCTOR OF SCIENCE IN ENGINEERING

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THESIS ON THE METHOD OF ERECTION EMPLOYED IN PLACING NEW STRENGTHENING GIRDERS ON CERTAIN IMPORTANT BRIDGES OF B. B. & C. I. RAILWAY SYSTEM IN INDIA.

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The object of this thesis is to demonstrate that in completely modifying the proposals for erection of the strengthening girders of these several bridges as put forward by the consulting engineers in London, who prepared the designs and scheme for erection, the maximum efficiency of the completed structure to fulfil the purpose intended under working conditions in India was thereby attained.

The Division of the B.B. & C.I.Rly. system on which this work was carried out is known as the Rutlam Division extending from Godhra mile 292, to Shamghar mile 490, on the main line running from Bombay to Delhi, the gauge of which is commonly known as Broad Gauge 5'6". The headquarters of the division are at Rutlam mile 408, and the author of this paper was the executive engineer of the division, who put forward the modified schemes and received the sanction of the Chief Engineer to put them into effect.

The bridges at which work was carried out were -

(1) The Mahi Bridge No. 226 at mile 384-2002' near Bhaironghar Station;

(2) The Chambal Bridge No. 317 at mile 432-433' near Nagda Station;

(3) The Anas Bridge No. 142 at mile 352-2587' between Stations Anas and Nahargarh;

(4) The Ghorakal Bridge No. 89 at mile 328-1248' between Stations Usra and Jekot.

The work started early in year 1925 and was completed in 1928.

General Remarks.

The introduction to the B.B.& C.I.Rly. system of the new P class passenger engines, and M. class goods engines in/

General Remarks (Contd.)

in 1924 called for either renewal of these bridges or strengthening to meet the increased axle loads, and the consulting engineers in London Messrs Rendel, Palmer Tritton, Victoria Street were requested by the Home Board to submit proposals to meet same.

Prior to this time the heaviest loading to which these bridges were subjected was occasioned by the engines then in use viz. the "G" and "H" class engines, averaging 16 to 17 tons axle loads, while the axle loads occasioned by "P" class amounts to 19¾ tons. Details of axle loads etc. of ~~both~~ "G", "H", "M" and "P" class engines are given in appendix "A" attached to this paper.

The consulting engineers after consideration came to the decision that the most economical manner in which to meet the demands of "P" & "M" class of engines as well as to provide for future requirements in the case of all these four bridges was not to regirder, but to provide additional or strengthening girders in each case, which in conjunction with existing girders could be relied upon to meet present and future demands and be up to B.B.& C.I. Rly. 1916 standard of loading. B. B. & C. I. Rly. 1916, Standard of Loading is equivalent to Government of India Standard of Loading for Railway Bridges of 1903 plus 55% (For details of Government of India Standard Loading of 1903 see Appendix "A").

The designs for these necessary strengthening girders for the four bridges were prepared by the consulting engineers as well as the method by which they were to be erected, and the necessary working plans describing the methods to be adopted duly despatched to India. These plans were duly received by the author and after scruting and consideration the author propounded the modified methods/

General Remarks (Contd.)

methods which he submitted to the Chief Engineer of the Railway should be adopted as being not only more economical, but (having in view the standard of Indian workmanship for this class of work) more efficient. The basis for this contention rested on the fact that the ultimate efficiency of the truss to carry out the work assigned to it depended largely on the efficiency of the riveting, and that whereas in the proposals for erection as proposed by consulting engineers most, if not all, the riveting to be done in India would require to be done in the air; in the proposed method of erection by the author all or the great majority of the riveting would be done on the ground, ensuring the maximum amount of close supervision and detection of defective work.

Since this thesis is only concerned with the methods of erection employed, no remarks are called for on the designs of the several trusses: As the methods of erection employed by the author in the case of the Mahi Bridge No.226 near Bhairongarh differs from methods employed in case of Chambal Bridge No. 317 near Nagda, Anas Bridge No. 142 between Anas and Nahargarh, and Ghorakal Bridge No. 89 between Usra and Jekot it is proposed to deal in detail first with method employed in case of Mahi Bridge, and subsequently in detail with method employed in cases of Chambal Bridge, Anas Bridge, and Ghorakal Bridge since the three latter bridges were practically similar except in so far as location to points of assembly were concerned, and the consequent difficulties that were, raised thereby. A detail of plant employed (with costs) in carrying out the work on all these bridges is given in Appendix "A" to this thesis.

METHOD OF ERECTION.

MAHI BRIDGE No. 226 mile 384-2002' near BHAIRONGARH

General Remarks. The existing Bridge consists of 2 spans of 100 ft. clear and 6 spans of 150 ft. clear, as per general elevation plan annexed with a rail level above water level at cold weather period of just over 90 feet.

The bridge is built for single track Broadgauge railway, existing girders being of N open web type on bearings fixed one end and free on rollers at the other end, supported on masonry piers 10 feet wide at top with necessary batter. The existing girders are 13'2" centres. The floor is carried on cross girders of built up web type and flanges carried on main posts immediately under top boom. Built up web and flange type stringers placed at 5'9" centres are bosomed into cross girders and carry the track with $\frac{3}{8}$" flat decking plate to form a floor. Wooden transverse sleepers at usual standard spacing carry the 90 lb. R. flat bottomed steel rails with standard bearing plates spiked to wooden sleepers in usual manner.

CEns. Drawing No. 7859)
CEns. Drawing No. 7820) These shew details of existing main girders and floor system.
Contract Drawing Sheet No.2 without No.)

The proposed method of erection made by Consulting Engineers are given in detail on their plans as enumerated below.

1st For 100 ft clear spans - Rendel Palmer & Tritton
Drawing No. P.F. 570
CEns.Drg.No. $\frac{60370}{38\text{-}D}$

2nd For preparatory work on existing spans - Rendel Palmer & Tritton
Drg. No. P.F. 571
CENs.Drg.No. $\frac{60371}{38\text{-}D}$

MAHI BRIDGE

General Remarks (Contd.)

3rd for 150 ft.clear span - Rendel Palmer & Tritton

Drg.No. P.F. 569

C.E.Ns.Drg.No. $\frac{60369}{38\text{-}D}$

Since the erection instructions given by the consulting engineers are clearly stated in the plans mentioned above, it is not proposed to state them in the body of the thesis, but for reference, a summary of these instructions is given in appendix "B" of this thesis.

MAHI BRIDGE. 100 ft Clear Span. New work.

Modified methods of Erection as actually carried out.

After consideration the method proposed by the author and adopted for erection of 100 ft. clear span girders of new work was as under.

For reference please see Working Drawing, Rendel Palmer and Tritton No. 6564/1 as made C.E.Ns. Drawing No. $\frac{61062.}{38\text{-}D}1$.

The preparatory work on abutments, piers and bracings etc. as specified and shewn on Rendel Palmer & Tritton's Drawing No. P.F. 571. C.E.Ns Drawing No. $\frac{60371}{38\text{-}D.}$ was started early in May, after receipt of necessary materials. The masonry of existing piers was cut away as required so as to provide necessary bed blocks for new bearings. This work was carried out under normal traffic conditions strutting timbers being put in until such time as new bed blocks were properly set. The bed block for new strengthening girders both at abutments and piers were given a depth of not less than 18 inches depending on courses of masonry and were constructed of mass reinforced cement concrete 1-2-4 mixture throughout the length of abutment or pier cut away.

In the case of the two 100 ft clear spans which were dry or shore spans, the ground immediately under the span for a width necessary to enable both girders to be assembled at once was levelled up to form a platform. The girders were assembled on a falsework of 12" x 12" oregon pine timber baulks placed to suit joints in the prone or flat position each girder with the exception ~~One~~ one end piece $U_0U_2L_1$ and member L1.L3. as shewn in above mentioned ~~place~~ plan. being accommodated between abutment and pier. This portion was service bolted and

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odified Methods f erection as ctually carried ut (Contd.)

had all bracing gussets possible in the scheme attached. The end piece indicated $U_0U_2L_1$ was assembled and service bolted(except member L_1U_2), to one side. All four 100 ft clear span girders were so assembled, and riveted up. The member L_1L_3 was placed after the whole girder and the portion $U_0U_2L_1$ had been erected complete and housed, and member L_1U_2 fixed in its place. Since the distance from rail level to level of assembling platform in case of new 100 ft. girders was not great no special lifting tackle was necessary and chain slings were used worked in conjunction with two 30 ton Locomotive breakdown cranes. After all necessary riveting had been completed in the case of the girders of these spans. The end piece $U_0U_2L_1$ was lifted up with auxiliary block and tackle (with the exception of member L_1U_2) and placed on its bearing at one end which had previously been set in its correct position. The free end of this piece was suspended by the special lifting tackle sent out by consulting engineers as depicted in Drawing No. 6441/7. To facilitate the lifting of girder from prone to vertical position six rail slides composed of 75 lb. flat bottomed rails well greased with a mixture of Russian tallow and graphite grease were fixed to six of timber baulks underneath girder. During the lifting from the prone to the upright position these greased rails permitted free sliding movement for bottom boom of girder until the vertical position was reached. After raising the girder to the vertical position it was propped and suitable slings substituted which did not interfere with the headroom available between top side of top boom of new girder and underside of existing stringers. The new girder or major portion of same was then raised with end as close to masonry of the pier as possible and brought up to as near as

ified Methods Erection as ually carried (Contd.)

as permissable to under-side of existing cross girders. The cranes were then traversed in direction of track sufficient to house the one end on to its bearing on to which it was then lowered, the other end which had been slightly lower being brought up into register at joint U_2. The members L_1L_3 and L_1U_2 were then fixed and fully service bolted making the truss complete.

All lateral and sway bracing after modification to suit new strengthening girders had purposely been left, service bolted, and this was removed prior to erection of strengthening girders, and replaced after second girder of each 100 ft. clear span had been duly erected.

Since the method adopted for riveting up the flange and web joints at U_2 and L_1 and diagonal members L_1U_2 and bottom boom member L_1L_3 corresponds very closely to the procedure adopted in 150 ft. clear spans for which it has been indicated in detail, it will not be gone into here.

150 feet clear spans - New Work.

For reference please see working Drawing, Rendel Palmer and Tritton No. 6580/1 as made, C.E.Ns Drawing No. $\frac{61369}{38\text{-}D}$ 1. and details, X.E.Ns. ~~Place~~ Plan No. $\frac{1157Z}{38\text{-}D}$

The height from rail level to ground where there were shore spans and to water in case of water spans for 150 ft. spans was such as to call for special consider-:ation in method of erection. The preparatory work in piers, bracings, stringers etc. of existing bridge as specified and shewn on Rendel Palmer and Trittons Drawing No. P.F. 571 C.E.Ns Drawing No. $\frac{60371}{38\text{-}D}$ with the exception of modifications to pier No. 5 from Godhra side (due to the upstream bed blocks of existing bridge having been found badly fractured calling for attention and renewal and which was dealt with as indicated in

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dified Methods Erection as tually carried t (Contd.)

in appendix "D" to this ~~paper~~ thesis) was carried out systematically after completion of abutments and piers of 100 ft. clear spans, and was ready well in advance of erection. New mass reinforced cement concrete bed stones 1-2-4 mixture throughout width and length of pier so modified to a minimum depth of 18" depending on courses of existing masonry were placed and finished off to true level to receive new bearings. The new bearings were all placed in exact position and alignment, and holding down bolts placed but left ungrouted.

As description of erection of Water spans of 150 ft. clear is treated separately we will deal now with 150 ft. clear shore spans, or those converted to shore spans by filling in.

The normal condition of Mahi River at Bhairongarh during cold weather period i.e. after monsoon (from about end of October) owing to there being a masonry weir thrown across the river to down stream side of this bridge to impound water for supply to locomotives gave four complete shore or dry spans e.g. both end or 100 ft. clear spans, and two 150 ft. clear spans from Godhra or south side, with two partial water spans viz. fourth span from Godhra or south side, (60 ft. approximately of which was water) and 7th span from Godhra or south side (30 feet approximately of which was water). Two complete water spans viz. 5th and 6th from Godhra side where depth of water ranged from 7 to 11 feet. As time was an important factor in the modified erection plan it was decided that where possible partial water spans should be converted into shore spans by rubble filling (obtainable at site) with a top dressing of sand (obtainable at site) leaving two complete water spans where owing to method adopted here (see detail for water spans) assembling and riveting of girder would

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involve greater time. Later owing to difficulty in procuring pontoons for erection of water spans and in order to save time span No. 6 from Godhra or south side was eventually converted into a shore span with rubble filling and top dressing since depth of water here was less than span No. 5. On all 150 ft. clear spans decided to be treated as shore spans necessary excavation and fill was put in hand both during monsoon and after monsoon when conditions permitted to prepare the necessary platforms, level or slightly graded to give the minimum amount of work in cut and fill and dressed off. The rubble fill of part water spans and span No. 6 from Godhra side was put in hand immediately after monsoon. The method of erection having in first instance been fully considered decided upon and written up in a log book in the possession of bridge foreman for his guidance. All the work not only of assembly, riveting and erection of girders pontoons etc. preparatory work, but preparation of platforms for shore spans was carried out departmentally under direct supervision of bridge foreman by native labour. It was decided in all 150 ft. clear spans to assemble girders complete side by side (with exception of water or Pontoon span) on 12" x 12" oregon pine baulks of necessary lengths placed to suit joints and properly levelled up with the exception of two end portions indicated on plan. Rendel Palmer and Tritton 6580/1-$U_0U_2L_2$. The girders were assembled on their flats top booms facing centre line of bridge. The gusset plates and posts U_2L_2 were attached to major portion of girder. This gave a length of approximately 131 ft. of girder accommodated on platforms between existing piers. For erection purposes the points at L_2U_2 as well as the portion of member U_2L_4

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)dified Methods Erection as tually carried it (Contd).

at its junction with bottom boom also the connection of gusset plates at M3 of this member were left fully service bolted both ends, the reason for which is indicated later when riveting after erection is treated in detail. The Girders during assembly were set to their proper camber and service bolted up to 50 %. Assembly went on systematically throughout, and riveting (all of which was pneumatic riveting) was carried out systematically span by span after completion of assembly. All bracing gusset plates etc. which could be fixed and riveted during this position and without interfering in any way with erection were fixed and very few had to be left off. The end portions $U_0U_2L_2$ were assembled separately just to one side at each end, and fully riveted up with the exception of member M_1U_2 which was left fully service bolted at junction M_1 for purpose of erection and tied up temporarily at junction U_2.

It was decided when erection took place that in first instance end portions $U_0U_2L_2$ should be lifted up by auxiliary block and tackle attached to existing bridge floor, by light wire rope hawser. These end portions would on erection be set true on their bearings at one end and at the free end be suspended from existing floor system by special suspension tackle provided by consulting engineers and shewn on plan Rendel Palmer and Tritton 6441/7, being thereby in its final position. To erect the major portion of main girder which as riveted up weighed approximately 34 tons it was decided to use the two 30 ton Loco Break Down Cranes. As these cranes had only a limited amount of hawser which would not permit more than a 30 ft. lift at outside, it was necessary to design a special lifting tackle which used in conjunction with these cranes would serve our purpose. Having decided to construct each 150 ft. clear span girder in three portions i.e. two end portions

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ıfied Methods Erection as ıally carried .(Contd.)

$U_0U_2L_2$ and major central portion the most effective method of erection was to place two end portions $U_0U_2L_2$ in their final positions and proper alignment and raise central major portion to register through these end portions until their top and bottom boom joints would synchronise and fully service up these junction points. This meant bringing up central portion in its final alignment immediately underneath the centre line of longitudinal stringers restricting the travel of 30 ton crane from rail level till rising pulley reached jib which at radius selected viz. 20 ft, gave a lift of just over 15 feet. The special lifting tackle to be designed to cooperate with 30 ton cranes in lifting girders from river bed to final position would have to be designed to meet this condition, and further, that should occasion arise when it might be necessary to suspend lifting operations to pass traffic before the girder had been lifted into final position and proper junction made with ends, the portion of new girder could be left suspended from floor system of existing bridge in such a manner that traffic could be passed after removal of cranes, without interfering with running dimensions, Plan X.E.N.s.No. $\frac{11572}{38\text{-}D}$ shews the design of lifting tackle adopted and detail of same required to fulfil all necessary conditions. The situation of Mahi Bridge at Bhairongarh being within the up outer and home signal of station it was possible to obtain the maximum amount of time between trains without great loss due to lead, when suspension of lifting operations had to take place. The operation of this special lifting tackle as the plan stated above shows was very simple and straightforward. It consisted of a special shackle to attach to 30 ton crane hook with two suspenders which registered into the short links of lifting tackle and took the load by means of pins $1\frac{1}{2}$" diameter. The lifting tackle proper consisted of a series of short links (14 inches

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lified methods Erection as ually carried (Contd.)

centre to centre of pin connections) and two long links registering into same (11'0" centre to centre of pin connections) one set on each side of rail bearers of existing bridge extending from rail level to lowest point to be lifted from. The pins between short and double long links were each 1⅝" dia true to size and a close sliding fit. In the centre of each short link there was a hole 3¼" full just to give clearance for insertion of a 3¼" diameter pin which pin during the process of removing a series of links each end took the load of central portion of girder being lifted. This 3¼" diameter pin rested in a cast iron block placed on top of stringer at point of suspension.

At the girder end of this special tackle there was a stirrup as per detail shewn in plan X.E.N. No. $\frac{11572}{38\text{-}D}$ which carried the top boom of new girder and which could be dismantled and removed when complete girder had been joined up. This special tackle it will be seen was so designed, that when it was necessary if such condition might arise to pass traffic either when girder was only partially lifted and suspended on 3¼" diameter pin through short links or fully lifted and suspended at short link attached to stirrup by 3¼" diameter pin these short links would not project more than 1⅝" above table of rail and giving ample lateral clearance so as not to interfere with any portion of running train. The extent of the lift at each operation as will be seen from the drawing was 12'2". Two complete such tackles one for each end of girder, were provided. It will be seen that the design of the special lifting tackle precluded its being put into operation until the central portion of girder to be lifted was in upright or vertical position, and auxiliary tackle had to be employed to lift the girder from its prone position to the vertical position. The tackle used for this operation consisted of Two special 3¼" circumference steel wire rope

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slings attached to top boom of girder just inside gusset plate at point U_2. These slings threaded through the eye of 21" treble sheaf blocks with 17" diameter pulleys and were held by $3\frac{1}{4}$" diameter steel pins. At the top or floor side of existing bridge was a 21" double sheaf block with 17" diameter pulleys, through the eye of which was threaded a specially constructed wire rope ring made from steel wire rope $3\frac{1}{4}$" circumference. Between this top pulley block near floor of bridge and treble sheaf pulley block at point U_2 of girder was threaded an endless steel wire rope $3\frac{1}{4}$" circumference, and the ends at the necessary length for lifting purposes held by a multiple plate clamp with 12-bolts. The same procedure was adopted at other end of span, the one length of wire rope serving both sides so as not to necessitate cutting, and to admit of reduction or extention as called for by varying heights from rail level to bed of river. All these clamps and slings were constructed at workshop at site. To meet this lifting operation a section of $\frac{3}{8}$" flat floor decking of existing bridge was cut out (to be afterwards replaced) some time previously. The double sheaf pulley block at existing floor of bridge each end of girder was suspended by temporary tackle at such a level below rail level (previously determined) as would ensure the girder to be lifted from prone to vertical position being brought fully vertical before the rising pulley of 30 ton crane had reached its ~~heighest~~ highest point. To facilitate sliding of girder to be lifted eight pieces of 75 lbs. flat bottomed rail were fixed to false work timbers and had girder resting evenly on same, prior to raising. These rails were well greased with a mixture of Russian tallow and graphite grease. When all was ready to lift girder to its vertical position the two 30 ton cranes were brought out and placed one at each end in correct position previously marked,

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crane hook lowered away to necessary level, to pick up wire rope ring threaded through eye of double sheaf pulley block. The strain at each end was then taken. To prevent undue deflection of top boom of new main girder until such time as girder was raised sufficiently high to develope its own stiffness, wooden packing pieces were inserted as lift took place at two points intermediate to points of suspension at point U_2. When girder was brought fully vertical in this operation it was approximately aligned to correct alignment, set down on timbers at sufficient points and propped.

Prior to lifting girder from prone to vertical position the stirrup end of special lifting tackle was fixed in its position just clear of auxiliary wire rope sling towards centre of girder at point U_2.

When girder was lifted from prone to vertical position and set the auxiliary lifting tackle was removed each end and slung ready for other girder of this span.

Two special lifting tackles were then lowered from the top or floor of existing bridge each end by exactly the reverse operation employed in lifting the girder, until sufficient tackle had been lowered away to register in with stirrup already in position each end.

Subject to traffic exigencies the operation of lifting the new strengthening girder central portion was now put in hand. All but three bays of transverse lateral and sway bracings as modified to specified plans and left service bolted having been removed prior to start of lifting from prone to vertical position of girder, these three bays were then removed and lifting started. The special shackle attached to crane hook was lowered to enable two suspenders to register in short links at each end and pins fitted. The load was then taken slowly and $3\frac{1}{4}$" pin through centre of short link on top of existing stringer withdrawn and lift carried on. Just prior to rising pulley of 30 ton crane

iified Methods erection as tually carried :. (Contd.)

reaching the jib of crane the second series of short links would come into register above the top of existing stringer, and 3¼" diameter pins ~~was~~ were then inserted and cranes lowered away until load was taken on these pins. The pin connections of long links to top of these short links were then removed and crane lowered until the pins attaching other short links above ~~to~~ two suspenders of special shackle attached to crane could be removed. This section of lifting tackle was removed each end and laid to one side. The special shackle with two suspenders was then lowered away to register again with short link and pins inserted, load taken, and 3¼" diameter pins removed, when everything was ready for next lift. This operation being repeated as often as necessary. If time was available when girder was brought up to rendering through end sections the operation was carried to a conclusion, the centre portion rendering through the end portions which were sprung slightly to facilitate rendering. When both top and bottom booms were in correct register the fixed end of span was brought finally home first, followed by the roller end; and after the experience of one or two girders this operation was very expeditiously carried out. Once in register at both ends a special gang of Khalassis both ends top and bottom boom fixed all necessary cover plates and angles and completely service bolted all joints, making the girder one complete truss. The cranes and other tackle was then removed and stirrup ends withdrawn by unbolting and lowered away to be fixed on second girder of the span.

The time taken when operating special lifting tackle to make one lift of 12'2" and be ready to start the next varied from 12 to 15 minutes, so that we could reckon on four lifts per hour. The time taken to make the joints of both top and bottom booms with end sections, after girder was in register was approximately one hour, and this under

ified Methods erection as ually carried . (Contd.)

traffic demand we brought on occasion down to fifty minutes. It was the usual practice to commence the lifting from prone to vertical position of girder at seven hours, and allowing for passing of scheduled trains, the operation of lifting complete, and making truss good was usually finished by 12.30 hours.

WATER or PONTOON SPAN.

As already stated spans 5 and 6 from Godhra or south side of bridge, being water spans, it was decided to assemble central portion of these girders on pontoons. Owing to delay in procuring the necessary pontoons from Bombay Development Dept. Government of Bombay, who had promised to give us the necessary pontoons and to save time, span No. 6 where the depth of water was not too great was converted into a shore span, by rubble filling and top dressing.

The Bombay Developement Dept. went back on their promise to let us have pontoons, but offered us the necessary number of lengths of pipe used for pumping their fill to meet our requirements instead, and these we arranged to take, and convert into pontoons.

These pipes were in 30'0" lengths and 3'6" internal diameter, and constructed of $\frac{1}{4}$" thick plate. Plan X.E.Ns. No $\frac{11643}{38\text{-D}}$ attached shews how these pipes were converted by insertion of necessary stiffening diaphragms, and end plates, and connected together to form a pontoon of 30 feet in length. Four such pontoons were constructed from twelve pipe lengths received. All work on pipes to convert them into pontoons as shewn on plan was carried out by bridge staff at site immediately after receipt of pipes and necessary materials for conversion, and in a most satisfactory manner.

Each section of 30 ft. of pipe was provided with a 3" dia. manhole on top together with a hole tapped to receive

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nipple of compressed air hose in the event of its being found necessary to pump out any water entering, or using compressed air to keep them watertight. Four such pontoons with outside pipes at 15'7" centres gave us a complete overall length of pontoon of over 120 feet, and with a margin between the pontoon sections sufficient length of pontoon upon which to assemble the central portion of new girder between the points U_2L_2 each end of centre. The various members of girder were floated out on rafts to complete pontoon which was satisfactorily anchored in nearly its final position, and assembly took place from centre towards both ends (upon double depth false work 12" x 12" oregon pine timbers to give necessary head room for riveting) so as to give equal distribution of load on pontoon.

Assembly and service bolting of girder on pontoon was carried out subject to foregoing conditions very much in similar manner to that of shore spans. After assembling and service bolting the girder was properly levelled up and riveting of all main joints of top and bottom boom put in hand, followed by web members. All gussets for sway and lateral bracing similar to shore spans which could be fixed were so done.

It was realised that conditions for lifting girder from pontoon would not be quite so simple as that from shore falsework, and in order to ensure stability it would be necessary to anchor the pontoon both for lateral movement and vertical movement. In order to ensure equal distri-:tion of load of girder throughout the bottom boom of girder and so facilitate sliding during raising, and minimise the deflection of top boom which had been noticed during raising of shore span girders during the first 6 feet or so of lift it was decided to fix the points of suspension of auxiliary lifting tackle described in detail for shore spans, not at

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point U_2 but between the points U_5 and U_6 each end thereby ensuring more even distribution of pressure throughout length of bottom boom. Twelve lengths of 75 lb. flat bottom rail slides (instead of eight as in case of similar shore spans) were suitably spiked to falsework timbers, two close together - one on each side of transverse angles tying pipes together so placed that two long bolts coming up through this angle, one near each end of timber, was fixed to a short angle piece resting on each timber and tightened up hard to prevent tilting of timbers or lateral movement. These rail slides took the weight of girder prior to lifting and were suitably greased as described for shore spans.

To prevent lateral movement of complete pontoon during raising two rings of sufficient strength were well grouted into masonry of each pier in the proper alignment and the ends of pontoon fixed to same by stout chains.

To prevent undue lift of pontoon at side where top boom of new girder rested while lifting was taking place the following device was adopted after pontoon had been placed in its final alignment. A temporary girder composed of two 75 lb. flat bottomed rails (placed ~~between~~ with flanges together and fully fish bolted and let into masonry of pier at each end a distance of 3 feet, grouted up with ferrocrete) was constructed, the alignment of which was clear of rising position of top boom but above transverse falsework timbers. This double rail girder above described was deflected by means of light tackle from floor of existing bridge to such an extent as to bring its natural resistance to further deflection into play, and the space between same and transverse timbers which it crossed was packed up hard to transfer this downward thrust to pontoon on this side.

In order to ease weight of bottom boom of new girder resting on pontoon and thereby facilitate sliding when raising from prone to vertical position the following device was adopted. Two chain slings were fixed round the

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(Contd.)

bottom boom at point L_6 both ends threading through the eye of double sheaf pulley blocks. Right above these points attached to bottom boom of existing main girders of bridge by similar chain slings were three sheaf pulley blocks. Through these pulley blocks bottom and top suitably clamped passed the necessary strands of strong flexible wire rope, being carried from each 3 sheaf block attached to bottom boom of existing girders of bridge through a change direction pulley on the left bank of the river and from there to two capstans suitably sited and anchored on the bank, and payed off beyond each capstan to a bollard. Prior to lifting, the sway and lateral bracing with the exception of 3 bays was dismantled and these three bays prior to pulling up of girder the same as in shore spans. The operation of lifting from the prone to vertical was started for this span at 6.30 a.m. in case of delays caused through unforseen circumstances. The two 30 ton cranes were brought into their positions over points of suspension previously marked. The hooks were lowered away through floor to pick up the ring of auxiliary lifting tackle and raised until both cranes were taking the strain. Before lifting was actually commenced by 30 ton cranes both capstans on the left bank were ordered to take the strain and carry a moiety of load of bottom boom.

This done the cranes were ordered to pick up slowly and as the top boom of girder was slowly raised the movement of pontoon was closely watched. After the cranes had picked up the top boom of new girder a certain height above its original level they were stopped and the two capstans on left bank of river were ordered to take a further strain. This was followed by a further lift by cranes. This method was employed until such time as the bottom boom of new girder had slid in towards centre line of bridge and was nearly over centre line of pipes of pontoon when the strain taken

lfied Method
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ually carried
(Contd.)

taken by tackle led to capstans on left bank was completely eased away. The remainder of lift until girder hung vertical was taken by 30 ton cranes only. Prior to lifting being started the stirrup of special lifting tackle had been fixed in its proper position each end just to centre line side of panel point U_2 and the special tackle had been lowered away from bridge to such length as was requisite.

The special lifting tackle was fixed while girder was suspended by auxiliary tackle at such a height that when lowered away the strain would be taken by the special tackle. This was successfully accomplished without any difficulty. All auxiliary tackle was then released and set in position for second girder. This portion of complete lift was completed by 9-15 hrs. when cranes had to be removed to pass a scheduled train. After passing of train cranes returned on bridge and took up new position above suspension points U_2 when the operation of lifting with special tackle was put in motion as already described in detail. The girder was lifted rendered through ends which were already in position as previously described, and joints fullyservice bolted making truss complete by 12-30 hours. The special devices described in detail employed to prevent lateral movement of pontoon, uplift of pontoon under raising of top boom of girder, and the auxiliary tackle used for easing the weight of bottom boom acted in each case exactly as anticipated, with the result that there was not a hitch in the operation from start to finish.

The second girder of this water span was assembled, riveted and lifted from this pontoon in an exactly similar manner, thereby completing the housing of every girder of bridge.

To complete the erection there only remains a description of method employed in riveting up these joints between ends and major portion of girder which were service

MAHI BRIDGE.

ified Method erection as ually carried . (Contd.)

bolted after lifting as already described in detail. All spans for this work were treated alike, the authpr will describe the process for one 150 ft. clear span girder. Plans of reference are

Working Drawings Rendel Palmer & Tritton

Drawings No. 6580/2 and 6580/3.

The joints to be riveted in the air are U_2, L_2, Bottom boom end of member U_2L_4, and gusset connection to U_2L_4 at point M3.

It will be remembered that in order to facilitate riveting up of the complete joints U_2 and L_2 with special reference to the flanges, the following connections were left bolted.

Bottom and top boom end of member U_2L_4

Gusset connection to U_2L_4 at point M3.

In the following description it should be clearly understood that only one new strengthening girder is dealt with at one time.

All lateral and sway bracings etc. connecting two new strengthening girders, and these to existing main girders have their service bolts eased to permit of free movement of girder being dealt with.Between the points U_2 at each end the new strengthening girder is supported at four points by moulmein oak timbers each 14" x 14" two such at each support, stretched across and resting on top of bottom booms of existing girders of bridge. The two outer supports being brought as near to joint U_2 as is practicable for riveting. Three twenty ton screw jacks are placed on these beams, under the top boom of new strengthening girder, and jacked ~~packed~~ up, and the weight of new strengthening girder taken evenly on same. The remaining support is packed up hard to this level. Both ends of new strengthening girder is suspended at joint U_2 by special tackle sent out by consulting engineers. When the top of boom of new strengthening

led Methods
ection as
lly carried
(Contd.)

girder has been set up by means of jacks and this suspension tackle to make it just proud to finished camber the service bolted joints at U_2 and L_2 is broken each end. In order to drive the rivets in top and bottom flanges at joint U_2 and L_2 it is necessary to move alternately, the members M_1U_2, U_2L_2, and U_2L_4 at each end, this being accomplished by means of temporary support at one end and pivoting about the other end of these members. A test of this method of procedure was actually carried out with a riveting hammer on the ground, with successful results. This enables the riveting of flange covers to be completed after which these members are again fully services bolted. The service bolts in these members are now removed one at a time and rivets driven until riveting is complete at both ends. On completion the jacks were removed, and transferred over to other girder, which is treated in a similar manner. On completion of riveting up of new strengthening girders, all lateral and sway bracing, also connections between existing girders and new girders, and floor plating have their rivets driven. The span is now complete and ready for the packings. One squad of riveters is employed per span on this work, and two spans are in operation at one time. The time taken to complete riveting per span by this method was approximately one week.

ackings.

Each 100 ft. clear span girder has 24 packings or 48 packings per 100 ft. clear span.

Each 150 ft. clear span girder has 30 packings or 60 packings per 150 ft. clear span.

On completion of riveting of each span and prior to placing of packing pieces a hardwood packing cut true is fixed at all places where packings are to be placed; throughout the span so treated before sunrise just to be a driving fit. These wooden packings are left in position for seven days under traffic and carefully watched to

MAHI BRIDGE.

Packing (Contd.)

ensure their acting as required. The pucca packings are then machined to the depths necessary as indicated by the wooden packings and fixed in place of wooden packings (with extra plates machined, and cut true to packing dimensions if found necessary). Each subsequent span is treated in an exact similar manner until whole bridge is complete. The only work remaining to be done is painting which was put in hand after fixing of packings.

Cost.

The average daily wage bill on the work comes to Rupees 80 per day, but this average dropped, since on completion of erection of all the girders one squad of riveters and a fair number of Khalassis were dispensed with. During and up to the erection of all girders there were approximately 24 Khalassis employed on the work.

The accompanying photographs 1 to 10 and snapshot photographs -1-24- - - shew clearly the methods employed in erection.

Plans general and detail as indicated in body of paper are also attached for reference.

Appendix "C" shews details of cost, and numbers of rivets driven in connection with Mahi Bridge.

Appendix "D" attached describes work involved in renewing cracked bed stones of pier No. 5 referred to in body of paper.

APPENDIX "A".

MAHI BRIDGE.

Details of "G" & "H" Class Engines.

"G" class superheated goods engine 2-8-0 type with coupled tender on 3 axles.

Weight of engine in working order - - 73 tons 13 cwts.

Weight of tender in working order - - 47 tons.

Weight of engine and tender in working order - - 120 tons 13 cwts.

Driving wheels 4'8$\frac{1}{8}$" diameter.

Centres of Driving Wheels - 5'7$\frac{1}{8}$" and 5'2$\frac{1}{4}$" respectively.

Axle Loads - 16 tons 3 cwts, 16 tons 7 cwts and 16 tons 4 cwts.

"H" class superheated passenger engine 4-6-0 type with coupled tender on 3 axles.

Weight of engine in working order - - 72 tons.

Weight of tender in working order - - 47 tons 3 cwts.

Weight of engine and tender in working order - - 119 tons 3 cwts.

Driving wheels 6'2" diameter.

Centres of driving wheels 6'9" and 7'6" respectively.

Axle Loads - 17 tons, 17 tons 3 cwts, and 17 tons 1 cwt.

Even under the running of "G" and "H" class engines no double heading was permitted over the Mahi Bridge No. 226 near Bhairongarh, and in case of Chambal, Anas and Ghorakal bridges double heading was only permitted under a speed restriction of five miles per hour over these bridges.

The details of "P" & "M" class engines introduced to the system of B. B. & C.Y. Rly. in 1924 is enumerated below.

"P"/

Appendix "A" (Contd.) 2.

Mahi Bridge.

"P" Class superheated passenger engine 4-6-2 pacific type, with coupled tender on four axles total wheel base 66'3½".

Weight of engine in working order - - 94 tons 4 cwts.

Weight of tender in working order - - 73 tons 11 cwts.

Weight of engine and tender in working order - -167 tons 15 cwts.

Driving wheels - 6'2" diameter.

Centres of Driving wheels - 6'4½".

Axle load 19¾ tons.

"M" class superheated goods engine 2-8-2 Mikado type with coupled tender on four axles wheel base 65'4½".

Weight of engine in working order - - 94 tons 13 cwts.

Weight of tender in working order - - 73 tons 11 cwts.

Weight of engine and tender in working order - - 168 tons 4 cwts.

Driving wheels - 4'8½" diameter.

Centres of Driving wheels - 5'6" and 5'1½" respectively.

Axle loads 17¾ and 18 tons.

Standard of Loading.

These existing bridges were most probably designed for a Government of India Standard of Loading for Railway Bridges prior to 1903 and it will probably not be out of place to indicate what this standard of loading for 1903 provides for, for a typical span.

Taking case of 100 feet clear span with centre to centre of bearings of 104'6".

Standard "B" of 1903 lays down.

Bending Moment.

Uniform vertical train load in tons per foot of each track to be used for calculating bending moments for effective span of 105'0" is - - 1.868 tons or total load 196 tons.

Appendix "A" (Contd.)

Mahi Bridge.

dard of
ing (Contd.) Shears

Uniform vertical load in tons per foot of each track to be used for calculating shears and traction and brake loads for effective span of 105'0" is - - 1·998 tons.

Cross Girder Reactions in Tons

For crossgirders 8'0" centres - - - 26·2 tons

Standard "B" of 1903 laysdown.

For spans of over fifty feet the increment for impact is to be calculated for steel and iron bridges under Railways of all guages by multiplying the train load by the factor - - - - - $\frac{300}{300 - L}$

lant. A description and cost of plant employed on all these bridges may be of interest as enumerated below.

All this plant with the exception of the ~~armoured~~ armoured. hose and wrought iron piping for riveting was obtained through the consulting engineers in London as specified by them in accord with the methods of erection proposed by them, and was all used except the item of two travelling steam cranes which with modified method of erection were found unnecessary.

etails of
Plant.

2 Travelling steam cranes 5'6" gauge to lift and travel under own steam with 10 tons in any position at 24 feet radius, complete with revolving and derricking gear, vacuum brake, screw hand brake, hinged buffers, and all fittings complete to specifications Makers Messrs Cowans Sheldon & Co. England @ £3325 each total £6650

2 sets Sling chains etc. as per specifications for above cranes - - - - - - - - - @ £47 each total £94

Appendix "A" (Contd.) 4.

MAHI BRIDGE.

ails of
nt (Contd.)

1 No. - 2 Cylinders 7"x8" Broom Wade Air Compressor to deliver 130 cubic feet free air per minute complete with all spares, ~~Semi~~ portable, furnishing power for four rivetting hammers. Rupees 6973 annas 11.

1 No. - Broomaster portable Air Compressor plant to deliver 92 cubic feet of free air per minute with air receiver and all spares complete, furnishing power for two rivetting hammers . - - - - Rupees 4909 annas 11.

Both above machines petrol

kerosine driven. Makers Broom & Wade, England.

4 Nos. Boyer Long stroke Rivetting Hammers No. 60 type

4 Nos. Boyer Long Stroke Rivetting Hammers No. 80 type

12 Nos. Lengths of ½" diameter armoured hose for above each length 25 feet. Rupees 2398.

4 Nos. Holders on Daisy "B" type over all length 6 inches all necessary snaps. ⅞" diameter Rupees 688.

Necessary wrought iron 1½" diameter piping with ~~mainfolds~~ manifolds for lead to compressors.

APPENDIX "B".

Erection Instruction.

Preparatory Work on Existing Spans.

(1) The existing cross frames are altered one at a time as shewn on the Cross-Section. New material has been supplied for all the central brackets, and for one cross frame per span. The angles for the remaining cross frames are to be obtained from existing materials. It is of utmost importance that all these diagonal angles be erected with their outstanding leg pointing towards the centre of the span.

(2) New angle stiffeners are to be fitted near the centre of the stringers as shewn. To facilitate work on site all the angles have had one end rounded to suit the root of the stringer angles, half the angles have been drilled with holes that connect to the web, while the other half have been left blank. All the packings have been drilled.

(3) The first rivets in the bottom flange of the end bay stringers in the gusset connections to the end cross girder are to be drilled out and replaced by rivets countersunk on the underside.

(4) The piers are to be cut away as shewn to suit the new bearings.

(5) The new main girders are to be erected separately in the following manner. The upper chord members are assembled underneath the deck on a temporary timber platform, supported by the existing main girders. This should be done at a height of about eight inches below the final position of the chord, and just off the longitudinal axis of the stringers. The top and bottom flange covers are now rivetted up complete, with the exception of the holes shewn as bolt holes. In order to provide head room for riveting, it may be necessary to slightly move the top chord in order to rivet under the cross-girders. No

Erection of New Work (Contd.)

gussets or web covers are to be riveted on at this stage, except gussets at the bearings.

(6) The top chord is now placed immediately under the stringers, raised to and supported at its final height by means of the lifting tackle shewn on Drawing No.6441/7. The bearings are now placed in position, thus supporting the ends of the top chord.

(7) The lifting tackle is now adjusted so as to produce a slightly greater camber than ---- inches in the top chord.

(8) The main gusset plates, web covers, and remaining members of the truss are now erected and riveted up as far as possible. The lower chord flange covers must be riveted on before the web covers. Should the holes for the closing length of bottom chord not be in register, the lifting tackle must be adjusted until it is possible to complete the truss.

(9) The girder is now self supporting, and the lifting tackle may be removed. The top chord should be temporarily connected to existing work in three places, in order to support it as a ~~street~~ strut.

(10) The second main girder is erected in a similar manner, cross frames inserted, and connections made to existing girders with bolts. All connections on the new work must now be fully riveted or bolted up so as to form a complete structure.

(11) The packings shewn between the stringers of the existing span, and the upper chord of the new main girders should now be prepared. The castings are machined to standard depths, and any difference required to accommodate the camber in the existing girders made up by steel plate packings machined to suit each individual position. The thickness of these making up pieces is important, and is best found by first filling hard wood packings and machining

Appendix "B" (Contd) 3.

Erection of New work (Contd.)

the steel packings to the same thickness. For very accurate work the hard wood packings should be fitted immediately before sunrise, when both new and existing work are exactly the same temperature.

(12) All connections between the old and new work will now be permanently riveted up.

APPENDIX "C".

MAHI BRIDGE.

ting and
s.

All rivets used were $\frac{7}{8}$" diameter and the average number driven per squad per day excluding stoppages outwith their control was approx. 300. All riveting was pneumatic. The total number of rivets driven ~~on~~ on the work exclusive of cutting out and re-riveting the decking plates cut out for purpose of raising is as under.

Shop Rivets (that is those in fabricated material received)

100 ft. clear spans - - - - - - - - - - -	8,600 numbers
150 ft. clear spans - - - - - - - - - - -	55,500 "
Total - - -	64,100 "

Field Rivets (or those driven in India on Work)

100 ft. clear spans - - - - - - - - - - -	12,700 numbers
150 " " " - - - - - - - - - - -	80,400 "
Rivets in modification of existing bracings and additions to existing bridge flooring system etc. for both 100 ft. and 150 ft. clear spans - -	8,800 "
Total	101,900 "

The estimated total cost of work was (including credit for plant 62751 Rupees) - - Rs. 314,164.

The actual cost as booked was. As I left India before the accounts were closed this figure could not be secured, but there was every indication that there would be a considerable saving on estimated cost.

The Book cost to date was - without allowing any credits for plant and materials - - Rs. 281,986

Appendix "C" (Contd.) 2.

MAHI BRIDGE

The actual labour charges from start of work at Bhairongarh till completion was	As I left India before final completion this figure could not be given, but all the girders were in position, and there only remained to complete certain riveting for some spans; fix packing, and paint new work. The cost of labour up to time of my departure was Rs. 25,220 and it was estimated that by time work was completed in every respect the cost would be approx. 28,000 Rs.
The total tonnage of steel in work (exclusive of packings) was - - - - - -	658 tons.

The fabricated steelwork was prepared and shipped by

Messrs The Patent Shaft & Axletree Co.Ltd.,

Wednesbury Staffs - England.

whose workmanship was very good.

APPENDIX "D".

BRIDGE.

In the body of paper where reference is made to the transformation of piers, a special reference is made to - pier No. 5 from Godhra side in which a defect was found, and it was decided to take the opportunity of work on strengthening to rectify matters herein so far as possible. The author thinks it might be of interest to enlarge on how this was done under traffic conditions.

Reference should be made both to XEN's plan No. 11581/38-D, and XEN's plan No. 11657/38-D to follow description given here.

It was realised that before altering the top of pier No.5 to suit the new strengthening girders something would require to be done to remove the risk involved in having a cracked bed stone under up-stream girders of both spans No.5 and 6 where they rested on pier No. 5 (where there were fixed bearings). It was decided before starting on modifications of pier to cut out and renew these fractured bed stones, but as masonry below bed stones was fractured for a distance of over 6 feet, a strengthening device was designed as shown on plan No. XEN 11657/38-D by means of which it was hoped the top of pier would be held together to act as a homogeneous whole. This was obtained, and fixed as shown on plan, and acted very satisfactorily. The work of dismantling existing fractured bed blocks was then put in hand according to XEN's plan No. 11581/38-D. In the first instance the masonry of bed stone was cut down on outside and inside to admit of R.S.Joint 18" x 6" by 55 lbs. (shown on plan) being placed. When this was done and these held by tie bars at end just beyond face of pier, arrangements having been made the span at one end was jacked up between trains and one bearing removed and the girder supported on R.S. joist 20" x 6½" by 65 lbs (as shown on plan) and requisite packing inserted - below the bearing of opposite girder. All trains during this repair work were called upon to

AHI BRIDGE.

stop dead at cautionary signal and proceed over the bridge at 5 miles per hour. The fractured bed stone was then cut out, and tie and reinforcing bars inserted as shown in plan between 18" x 6" joist. Ferro crete cement concrete in proportions 1 - 2 - 4 was then placed between dotted lines shown to requisite level. After requisite time viz. one week, the span was lowered on to this new bed block, and the exact same procedure was followed for other fractured bed block. On completion of whole, these temporary R.S. joists were removed, and the face of bed stone by reinforcing elements originally put in. The opportunity was taken when existing bed stone, had been cut out to grout up fissures found in top of pier by means of a cement gun, worked off air compressors, and it was found by means of coloured water that some of these fissures went considerable way down the pier as disclosed by where water came out on to face of masonry - After completion of bed blocks, the modification of pier top to suit bearing of new strengthening girders was put in hand and completed. The stiffening girder arrangement as per plan No. XEN 11657/38-D, it was agreed should remain as a permanent fixture on this pier.

It might be noted here that with the exception of work on modification of pier No.5 for bearings of new strengthening, the similar work executed on all other piers and abutments was carried out under ordinary traffic arrangements without any speed restriction, by necessary shoring protection to eliminate vibration effect until concrete was properly in situ.

MAHI BRIDGE

(1) View of 150' Clear Span Girder in Prone Position

(2) 150' Clear Span Girder Suspended By Special Lifting Tackle

(3) 150' Clear Span Girder Being Raised by Special Lifting Tackle.

GE.

(4) Another View of Lifting 150' Clear Span Girder

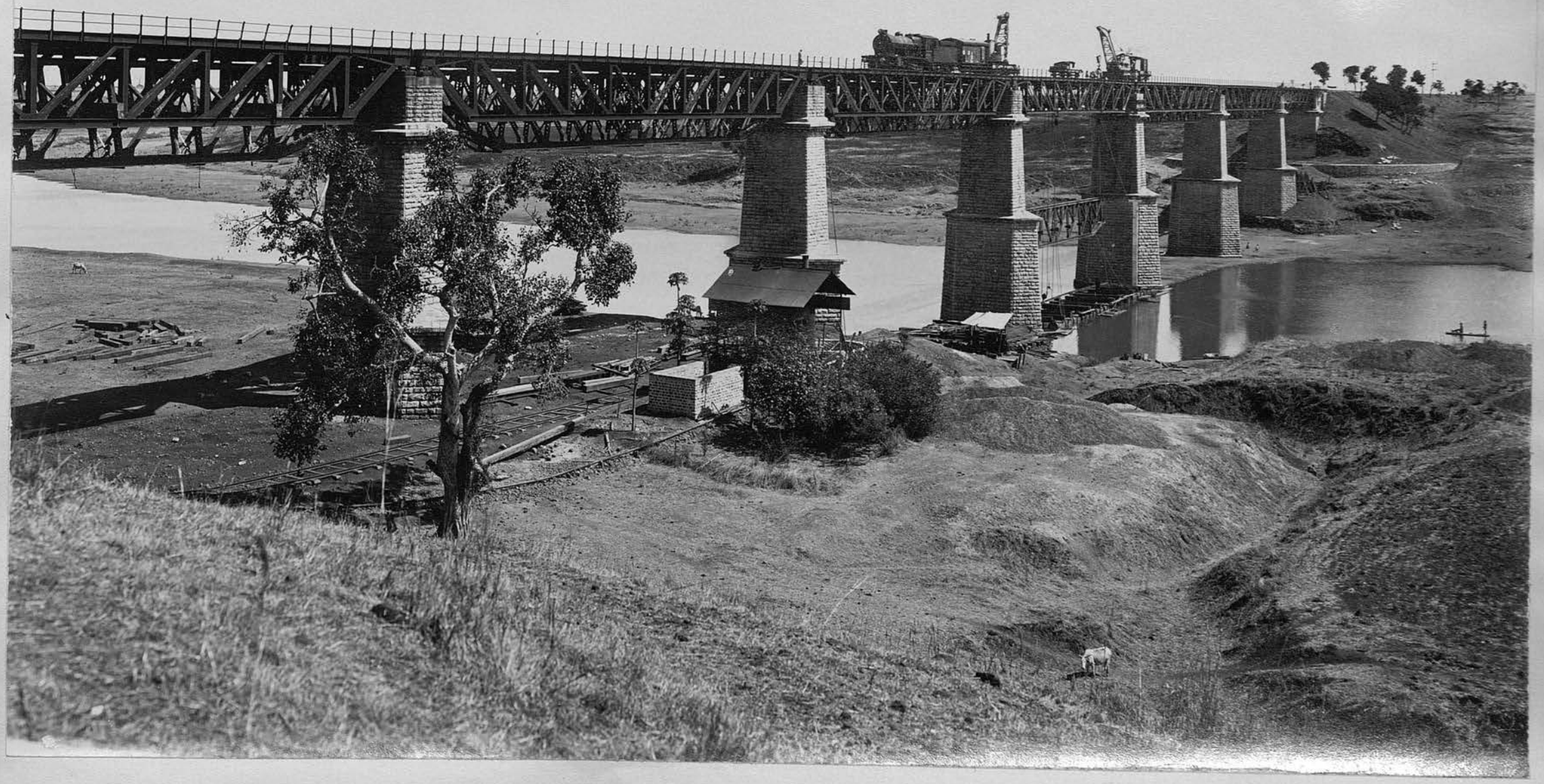
(5) 150' Clear Span Girder Nearing The End of Its Lift By Special Lifting Tackle.

(6) General View – Water or Pontoon Span. – Girder Resting on Pontoon

(7) Pontoon Span. Raising Girder from Prone To Vertical Position by Means of Auxiliary Tackle.

41.

OGE.



(8) General View of Strengthened Bridge Nearing Completion Girder of Water Span Being Lifted.

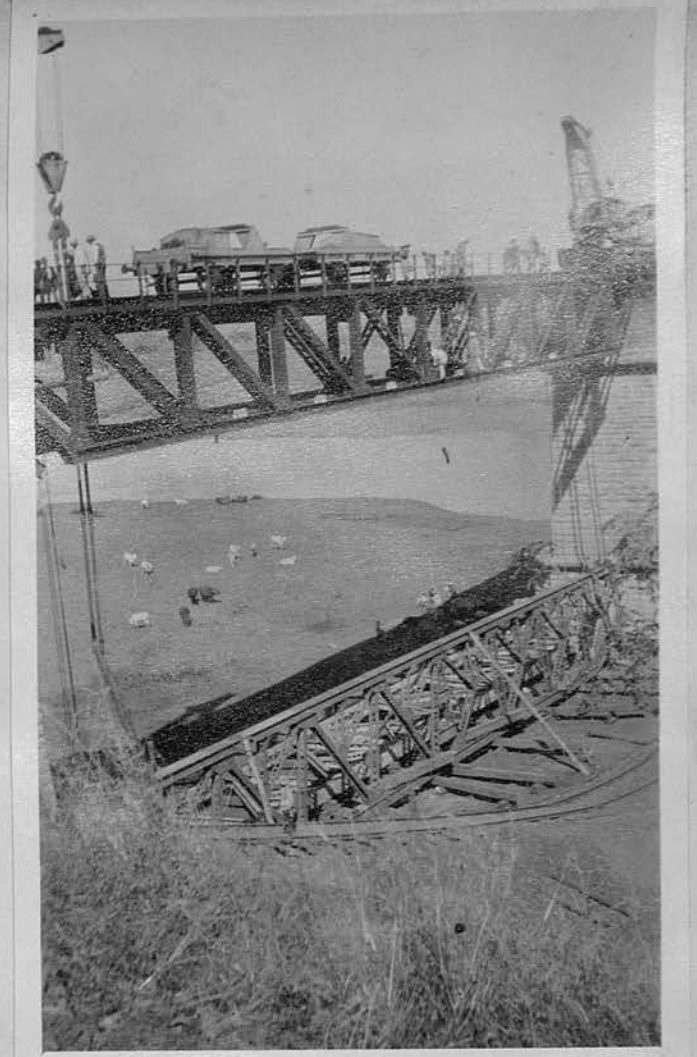
(9) Girder of Pontoon Span Nearing final Position. Shews Double Rail Girder Device for Anchoring Pontoon.

GE.

(10) General View from Underneath Shewing New Strengthening Girders and Bracing

Mahi Bridge.

(1) General View of Bridge Prior To Strengthening



(2) 150' Girder Propped after Lifting from Prone Position.

(3) 150' Span Girder Propped Shewing Fixing of Special Lifting Tackle.

(4) Raising Girder By Means of Special Lifting Tackle.

MAHI BRIDGE.

(5) Another View of Girder Being Lifted.

(6) Girder Nearly Lifted.

(7) View Shewing Passing of Passenger Train With New Girder Suspended.

(8) Girder of Another Span Being Lifted

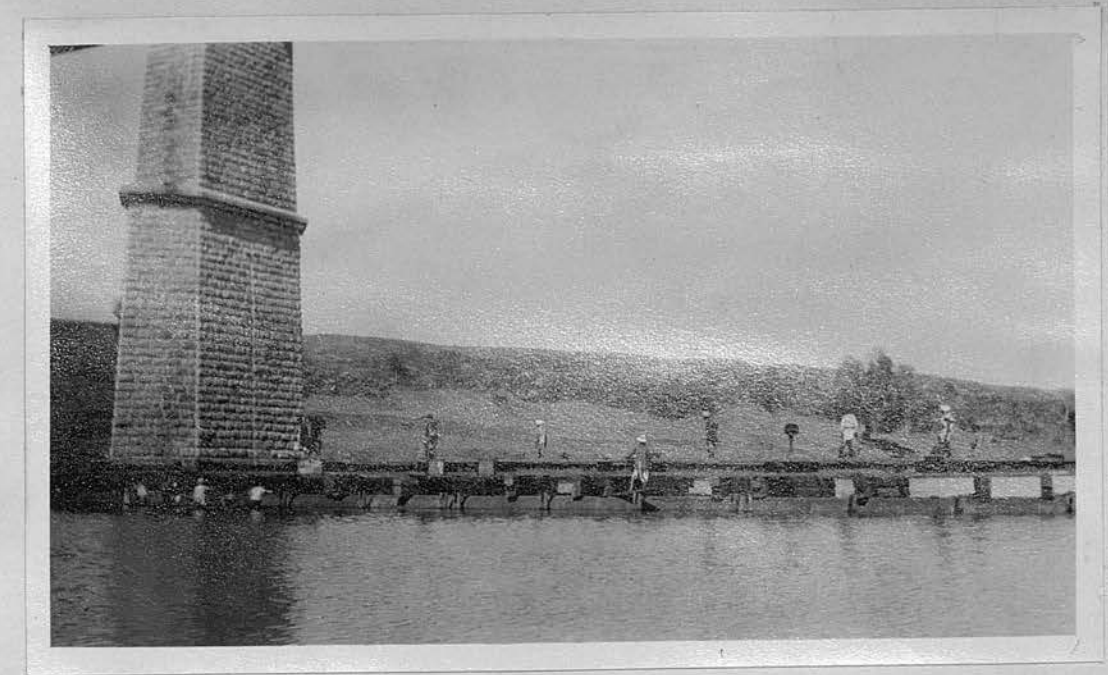
(9) Lifting Girder of Span No 7.

(10) Another View of Lifting Girders of Span No 7.

(11) Span No 7 Girder Nearly Up.

(12) Span No 7 Girder Being Threaded Through Ends.

Mahi Bridge.



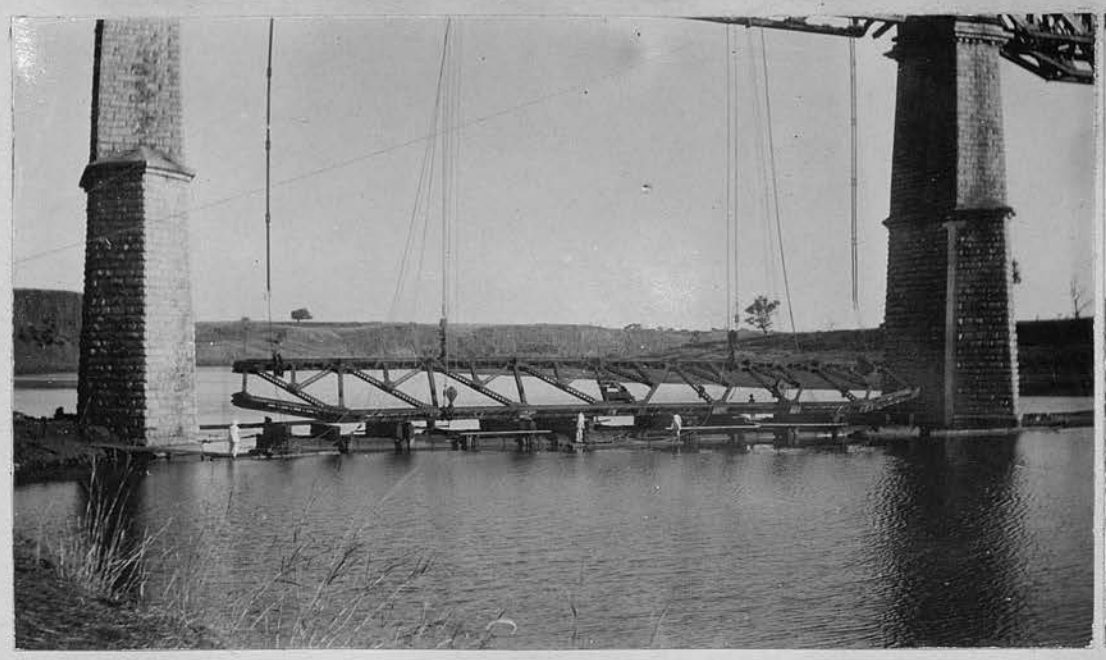
(13) Pontoon or Water Span. Assembling Girder

(14) Pontoon Span. — Riveting Girder

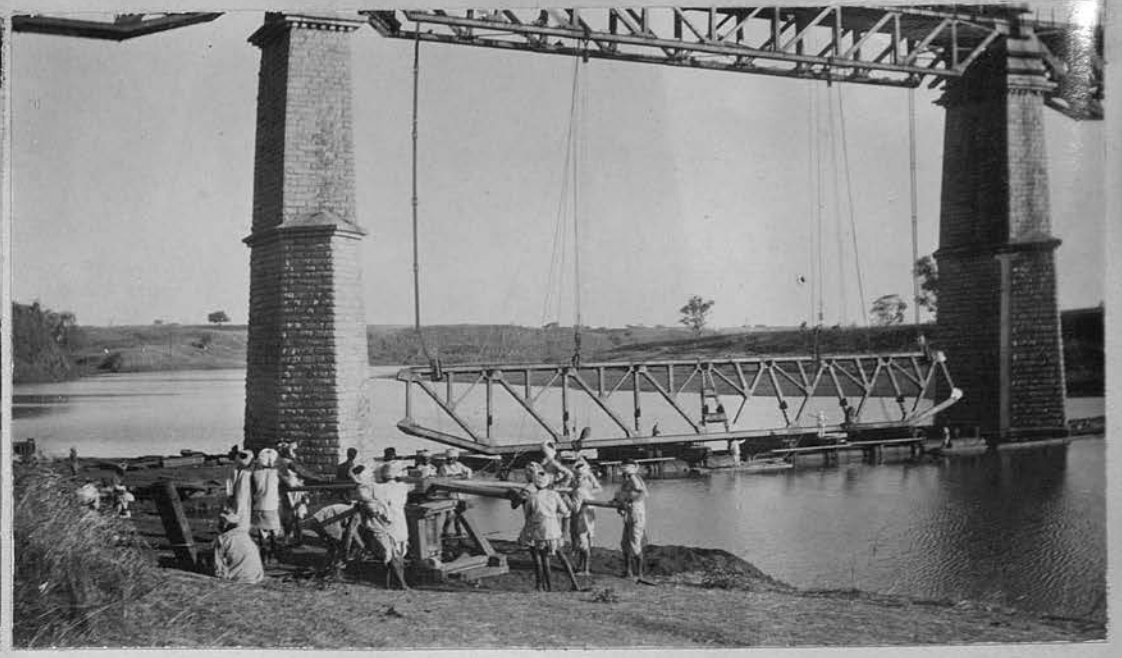
(15) Pontoon Span. Raising from. Prone To Vertical Position. By Means of Auxiliary Tackle.

(16) Another View.

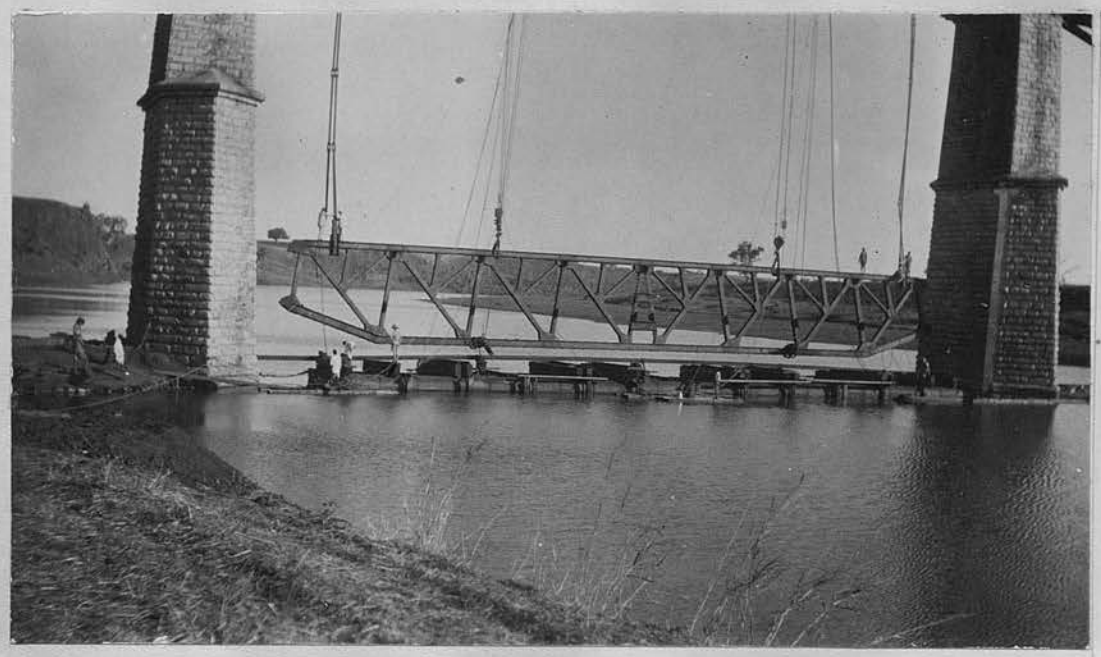
MAHI. BRIDGE.



(17) Pontoon Span. – Another View of Raising from Prone Position By Aux. Tackle.



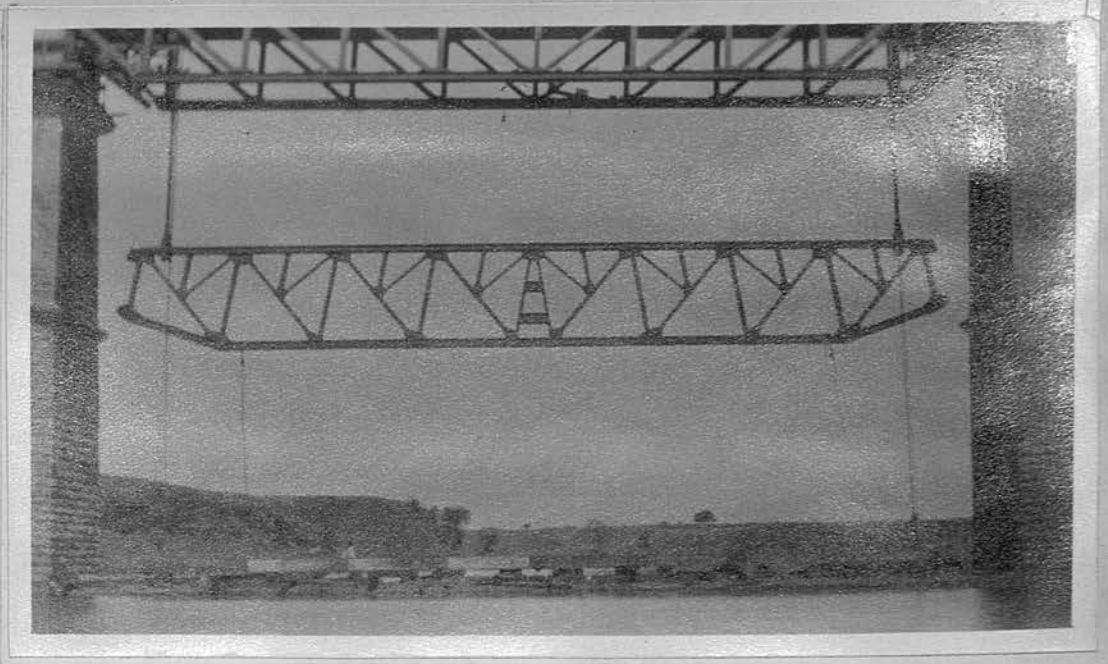
(18) Pontoon. Span. – Girder in Vertical Position.



(19) Pontoon. Span. – Fixing Special Lifting Tackle

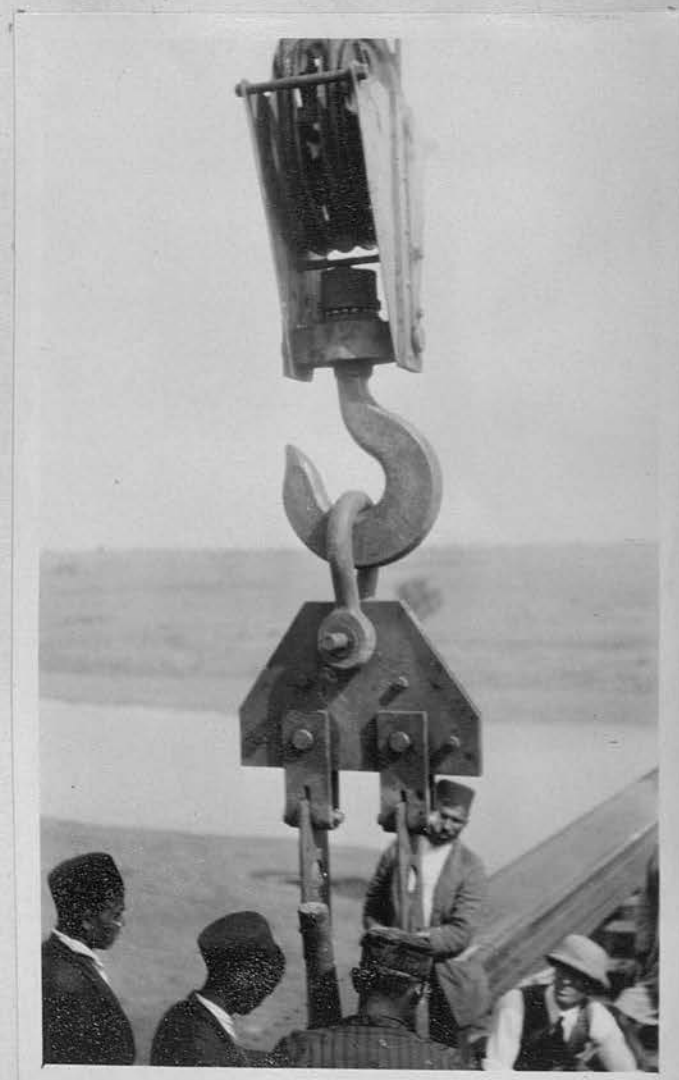
(20) Pontoon Span – Girder Suspended By Special Lifting Tackle.

(21) Pontoon Span.- Lifting Girder With Special Tackle.



(22) Another View of Lifting Girder - Pontoon Span.

Close Up View of Special Lifting Tackle in Operation.



(24) Another View Shewing Shackle.

CHAMBAL BRIDGE No. 317 mile 432-433' near NAGDA STATION.

eral marks. Since the Chambal Bridge No. 317 at Nagda, the Anas Bridge No. 142 at mile 352 -2587' between Anas and Nahargarh stations, and the Ghorakal Bridge No. 89 at mile 328-1248' between Usra and Jekot stations are practically of similar type except that in case of Anas Bridge it has one span of 60 ft.clear the author proposes to take the Chambal Bridge and describe the method adopted in detail since this method was adopted for all three, and conclude with a few general remarks about the Anas Bridge and the Ghorakal Bridge.

neral escription. The existing Chambal Bridge consists of ten spans of 100 ft. clear, as per general elevation plan annexed, with a rail level above bed of river of approx. 55 feet.

The bridge is built for single track Broad Gauge railway, and is of the deck type, the existing girders being of N open web type on bearings fixed one end and free at the other, supported on masonry piers similar in type to piers of Mahi Bridge. The existing main girders in this and the other two bridges are placed at 8'0" centres, and flooring consists of stout U type built up trough flooring 14'3" wide placed transversely across these girders. This trough flooring carries the wooden transverse sleepers at usual spacing on which with suitable bearing plates the 90 R lbs. flat bottom rail is carried Hand railings both sides are provided at the end of the troughing and fixed to same as shewn on plan. The depth of existing main girders over flange angles is 9'3".

The consulting engineers Messrs Rendel Palmer and Tritton decided as in case of Mahi River Bridge that the most economical way to meet the new loading called for by the "P" & "M" class engines was not to regirder, but to provide

CHAMBAL BRIDGE

1 Design d.)

additional strengthening girders placed outside the existing main girders with cross girders passing underneath bottom of top booms of existing girders, and connected to posts of new strengthening girders. Packing pieces between underside of top booms of existing main girders, and cross girders of new system distributed the loading to new strengthening girders. This would bring the strengthened bridge up to B.B. & C.I. Rly. 1916 standard of Loading or Government of India Standard of Loading for Railway Bridges of 1903 plus 55%.

The modification, put forward by the author, of the proposed method of erection for these three bridges as put forward by the consulting engineers in their plans had the same end in view as indicated in my remarks covering this point in its application to the Mahi Bridge, and although the Chambal Bridge was only 54 feet above bed of the river in the case of Anas Bridge the rail level was nearly 120 feet above the bed of the river.

The following plans are attached for reference

Plan X.E.N. $\frac{11844}{38\text{-}D}$) Shew detail of existing

" X.E.N. $\frac{11845}{36\text{-}D}$) 100 ft. clear span girders.

Rendel Palmer and Tritton's plans No. 6312/1 and 6425 (1 to 8) 6409 (1 & 2)

working drawings for new strengthening girders.

Drawing No. Rendel Palmer & Tritton P.F. 435 shews method of erection.

In the case of the Chambal Bridge it was found that ordinary coursed rubble masonry had been built up outside the ashlar bed blocks of existing girders and as the width of this masonry outside the bearings of existing girders was not great, and likely to disintigrate by vibration when new girders were seated there, it was decided to cut this all

CHAMBAL BRIDGE (Contd.)

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away both in piers and abutments up to ashlar bed block of existing girder, and to a depth of two courses below level of bottom of same, and fill in with reinforced cement concrete 1 - 2 - 4 mixture in mass, tied into existing bed blocks by stout steel dowls. This was carried out prior to commencement of steelwork throughout the bridge, under a speed restriction of five miles per hour. In the case of the Anas Bridge the piers were of such length as to give ample room for bed blocks of new girders, and the necessary masonry was just cut away and substituted by mass reinforced cement concrete blocks of 1 - 2 - 4 mixture. The erection instructions supplied by consulting engineers are shewn in appendix "A" attached for reference.

A close perusal of the plans submitted by the consulting engineers and the detail of the complete truss, as well as an inspection of actual existing conditions led the author to conclude that he could with every hope of success succeed in eliminating all the details proposed by the consulting engineers and erect girder in one operation. Before actually deciding the following points required to be made clear.

(1) Whether the 30 ton Loco Breakdown Cranes with the jib at a workable radius had sufficient head room with the rising pulley up at its highest point between the hook of crane and table of rail to permit of these new girders being slung and travelled with.

(2) With our girders slung in the required position what was the maximum amount of slew the cranes in question would give in order to determine whether it could clear the trough flooring of our existing bridge.

(3) With the new girder bearings in their position was there sufficient clearance between underside of end plate of troughing and top of pier to house the ends of our girders

CHAMBAL BRIDGE.

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before fouling these bearings.

(4) What arrangement as regards movement of sections of trough flooring of our existing bridge would be necessary to enable our slings to travel in over the bearings, and was it practicable.

Full consideration of all these points shewed that there was nothing to prevent its being put into practice, although investigation clearly indicated that in quite a few points there would be little left to play with especially in regard to item (2) where with the girder acting as a rigid chord between the two cranes, and comparatively short distance between the rising pulley and jib of crane it was realised the older crane of the two might not hold the slew, but after a trial it was decided that we could meet any such difficulty sufficient to ensure success.

Again the clearance between the underside of the end plate of trough floor of existing bridge and bearing of new girder was very neat, but with two such efficient cranes in good hands, it was felt this only wanted the exercise of care.

On approval of this modified method of erection being obtained from Chief Engineer a girder yard was laid down at Nagda station which was about a mile from the bridge (similar to that shewn on plan attached for Anas) and necessary workshops erected. All girder were assembled one after the other in this yard, in their prone position supported on 12" x 12" oregin pine timber baulks, and properly levelled up, and service bolted. All riveting was done here by pneumatic riveting hammers same as used on Mahi Bridge at Bhairongarh.

Prior to picking up girder from prone to vertical position rail slides, six in number consisting of 75 lb.

CHAMBAL BRIDGE.

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flat bottom rails were placed under girder on top of selected timbers, and properly greased. To pick up girders to vertical position chain slings were used and point of suspension was approximately three panel points in from bearing at each end. The two 30ton Loco cranes were used to pick up at these points and when girder was ~~brought~~ both raised and slewed in as far as practicable, one end was lowered and propped while other end was still in sling. At lowered end the crane hook was released and crane moved back to pick up sling already placed about 3 feet from bear-:ing. This end was slung and the other end lowered propped and crane moved back to the final slinging pos ition. The girder was then slung in between the cranes over centre of track, and timber baulkd, one at each end fixed in between crane buffer beam and bottom boom of new strengthening girder. The crane jibs set at the fixed radius, and all ready to proceed to the bridge.

At the bridge site all bearings were set true to their final positions, and the rivets of the necessary bays of trough flooring to be moved having been cut out previously, on the day when girder was being brought out these bays were pulled over to one side away from side where girder was being placed and as far as to be flush with flange of exist-:ing main girders, giving thereby ample room for slings of crane to operate. The hand railing had of course throughout been dismantled in advance. For purpose of convenience of traffic it was arranged to block the line for erection each day when same took place at same time. The forenoon was utilised to sling the girder ready to go to bridge, and actual work of placing took place in the afternoon at 14-45 hours. To expedite work marks were made on each span on the side of each rail where the cranes should come to rest with a known jib radius. After receipt of block the two cranes with

CHAMBAL BRIDGE.

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girder slung between them were pushed out slowly by an engine to the bridge and on arrival at span concerned were stopped dead on mark. The cranes were then propped in usual manner and shoes fixed, and girder slung out to desired side just to clear the troughing, lowered away until top of top boom was just clear of end plate of troughing, and then slewed in over its bearings. The fixed end was then adjusted until directly over its bearing and seated, followed by the free or roller end. The average time taken from the arrival on the bridge span until the girder was resting on its bearings complete was 30 minutes. Temporary chain sway bracing was fixed at both ends and centre between existing girders and new girders until such time as second girder of span was placed and cross girders, and wind bracing fixed.

This procedure of erection was followed throughout the whole bridge without the slighest hitch. So soon as all riveting in the girder yard at the station was complete, the riveting squads were transferred to the bridge where the cross girder connections, wind bracing, sway bracing, and re-riveting of trough flooring sections displaced, and hand railing were put in hand span by span, after their various items had been duly placed and service bolted. On completion of this work the hard wood packings were then placed as indicated in erection notes of Consulting Engineers span by span and after some time under traffic the C.I. packings were prepared to correspond and fixed with packing plates where necessary.

It is interesting to note that whereas we required twenty line blocks to complete erection, had the proposals of consulting engineers been carried out eighty line blocks would have been required.

CHAMBAL BRIDGE.

The accompanying photographs 1 to 6 and snapshots .1.-2..... shew clearly the methods adopted in erection.
Plans as indicated in body of paper accompany same shewing details, and instructions of consulting engineers as to how erection was to be carried out.

Appendix "B" attached to this paper shews details of rivets driven, and cost of work as estimated and completed, also tonnage of steelwork etc.

APPENDIX "A"

CHAMBAL BRIDGE.

Erection Notes as supplied by Consulting Engineers

Reference Plan P.F. 435.

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ERECTION NOTES.

(1) New cross girders are slung from the top chords of the existing main girders at approximately their final positions longitudinally (as shewn near the centres of the bays of existing main girders) at varying heights to give the necessary camber to the new main girders plus an amount to allow for the final closing of the joints. The varying heights must be given by timber packings inserted between the New Cross Girders and the existing Top Chords. These wedges also prevent tipping.

(2) New Main Girders should be erected in four sections shewn in elevation, the intersections being first riveted. They can be lowered over the side of existing span on to false ends attached to the New Cross Girders.

(3) When the four sections have been lowered and placed in line on the cross girder ends, the bottom chord joints should be made, and the flanges at least riveted. The other main girder is then to be dealt with in a similar manner.

(4) All the cross girders are then slacked down by the screwed rods provided just sufficiently to make the joints butt. The main Girders ~~are~~ are then riveted up complete still supported on the noses.

(5) The completed main girders are then traversed inwards to their correct longitudinal position. When being traversed the ends must pass over the tops of the bearings.

(6) The girders are then lowered simultaneously till they touch the bearings. A temporary connection must now be made between the new and existing girders at the centre of the span as indicated. This connection must remain in until the new girders take their full dead load and until the new Cross Girders are riveted up.

CHAMBAL BRIDGE.

Appendix "A" (Cont.d)

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(7) The wind bracing system between the bottom Chords of the New Main Girders should be inserted immediately after the new girders take their dead load on the bearings. Connections shewn on the drawing between the lower chords of the existing girders and the vertical posts can then be put in and adjusted.

(8) The cross girders are now brought in their correct position one at a time and riveted up.

(9) The cast iron packings shewn in Drawing P.F. 436 are to be planed at bottom to fit the spaces left between the new Cross Girders and the underside of the top chords of the existing span. The thickness of these packings is important, and is best found by first fitting a wooden packing for each block and afterwards machining the Cast Iron packings to the same. For very accurate work the wooden blocks should be fitted in immediately before sunrise,so that both old and new are at exactly the same tmeperature. The blocks as shewn are easily attached as no drilling is required to be done at the site.

APPENDIX "B"

CHAMBAL BRIDGE.

reting & Costs.

All rivets used on new work were $\frac{7}{8}$" diameter and riveting was pneumatic throughout.

The approximate number of such rivets for this bridge driven in India were

(1) Rivets driven in girder yard at Nagda station	62,000 Nos.
(2) Rivets driven at site of bridge excluding rivets driven in replacing trough flooring displaced and hand railing - - - - - - - - -	7,700 Nos.
Total	69,700 Nos.
Average No. of rivets driven per squad per day	250 Nos.

The Cost of Work on Chambal Bridge as estimated including provision of 25% depreciation of cost of plant was - - - - - - - -	Rs. 257,627
The actual cost as booked was - - - - - - - - -	Rs. 189,751
The actual cost in Labour incurred from time of receipt of material at Nagda till completion was approximately - - - - - - - - - -	Rs. 15,306
The total tonnage of steelwork employed on work exclusive of packings is - - - - - - - -	515 tons.

The fabricators of steelwork were

Messrs Freid Krupp-Rheinhausen Germany

Their workmanship was good.

CHAMBAL. BRIDGE.

(1) General View Shewing Bridge after Addition of Strengthening Girders.

CHAMBAL BRIDGE.

(2) Close Up View of Bridge After Addition of Strengthening Girders.

CHAMBAL BRIDGE.

(3) New Strengthening Girder Slung Between Cranes In Girder Yard.

CHAMBAL BRIDGE.

(4) General View of Girder Yard. Shewing Slung Girder Ready To Proceed To Bridge.

CHAMBAL BRIDGE.

(5) Arrival of Strengthening Girder Over Requisite Span of Bridge.

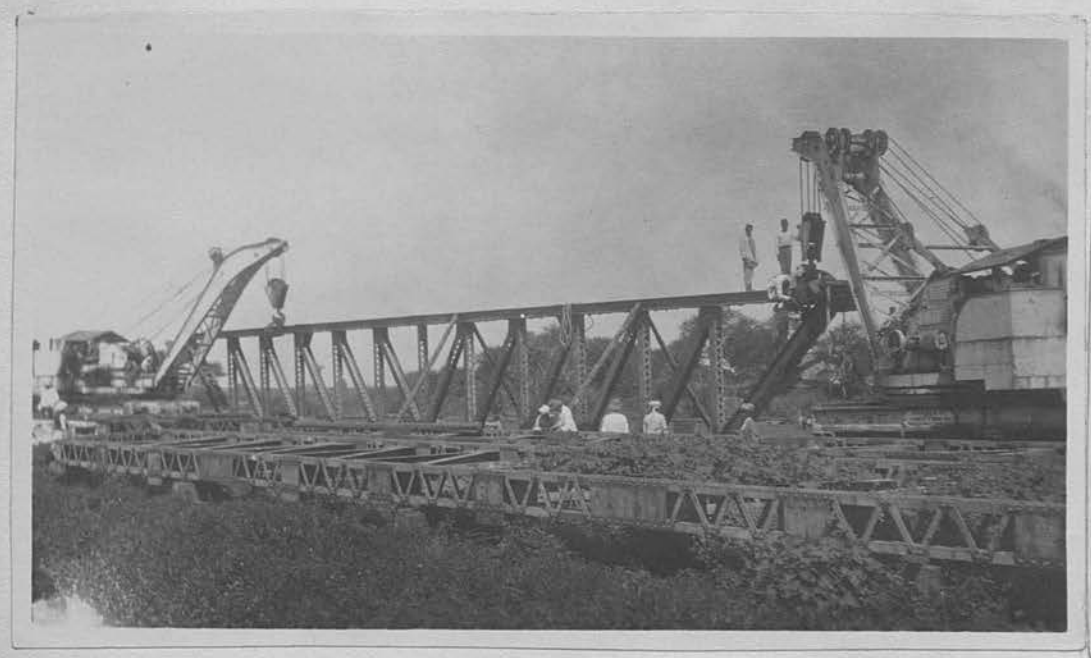
CHAMBAL. BRIDGE.

(6) Lowering New Strengthening Girder Into Position on Bridge.

CHAMBAL BRIDGE.

(1) General View of Bridge Prior To Strengthening

(2) Slinging New Girder In Girder Yard.



(3) Another View of Lifting & Slinging New Girder

(4) Arrival of First New Girder On Bridge.

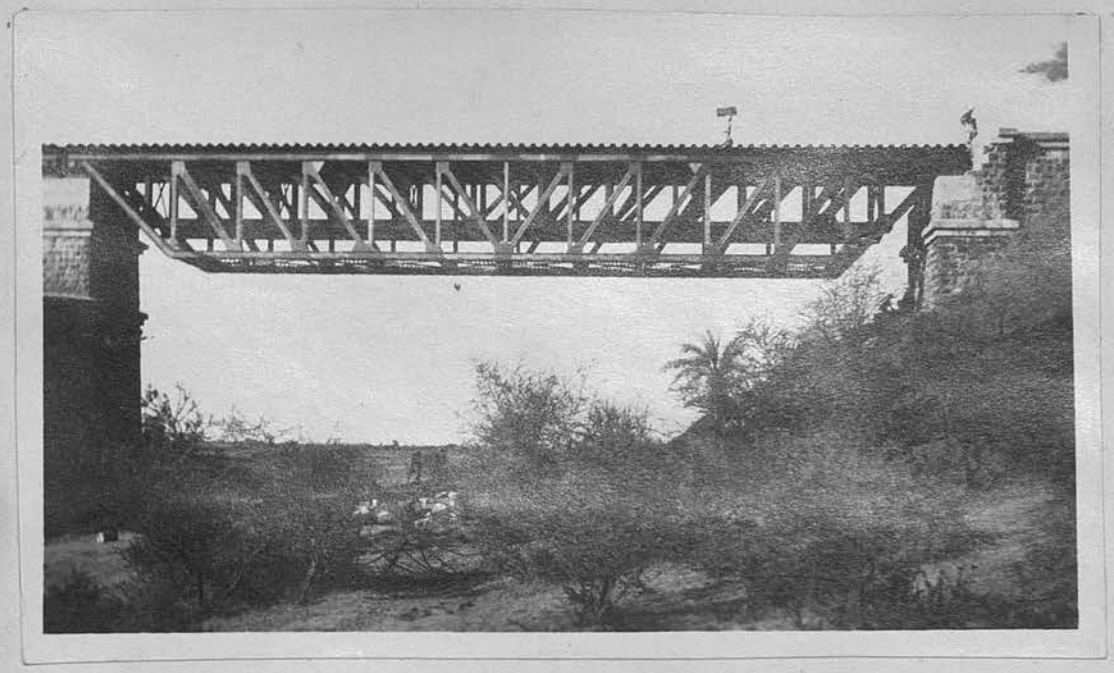
CHAMBAL BRIDGE.

(5) Girder Slung Ready To Proceed To Bridge.

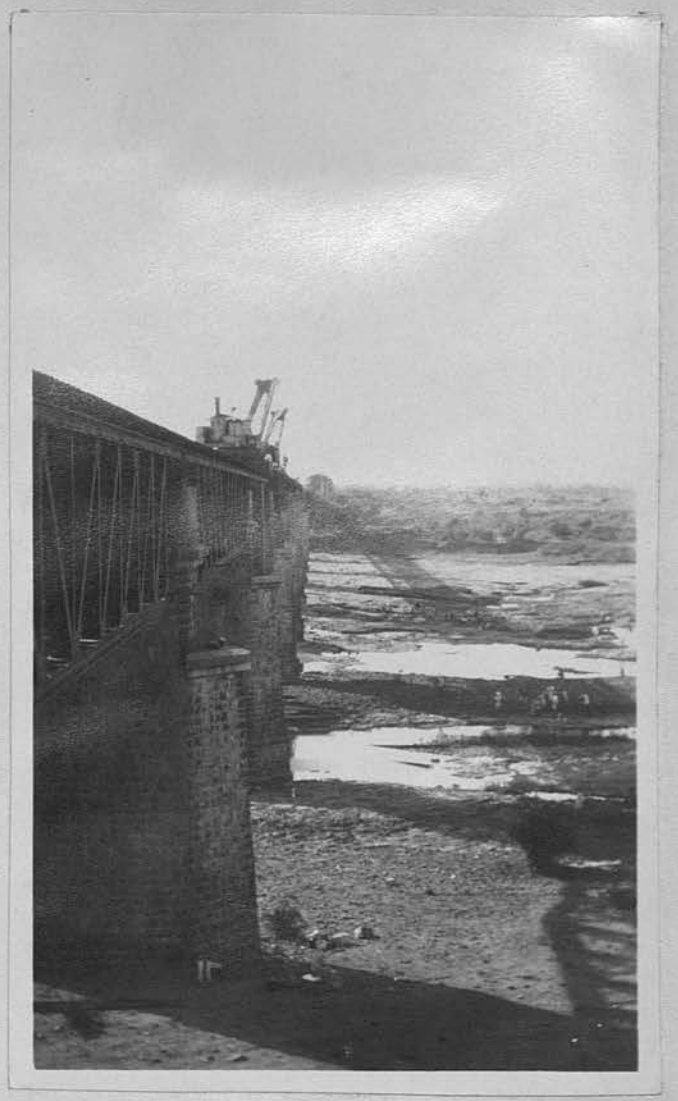
(6) Lowering Away New Girder Into Position On Bridge.

(7) View of Girder Yard.

CHAMBAL BRIDGE



(8) Close Up of One Span Shewing New Strengthening Girders



(9) New Girder Being Lowered Over Side Into Positio

ANAS BRIDGE No. 142 at mile 352-2587'
between Anas and ~~Ghorakal~~ Nahargarh Stations.
Ghorakal Bridge No. 89 at mile 328-1248'
between Usra and Jekot Stations.

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eneral Remarks.

These two bridges are exactly similar in type to Chambal Bridge already described in detail so there is no need to go into such detail for them. They both carry single track of Broad Guage main line. The Anas Bridge consists of 7 spans of 100 ft. clear and 1 span of 60 ft. clear and the Ghorakal Bridge consists of 1 span of 100 ft. clear.

The method of erection employed by the author for the Chambal Bridge was therefore employed in erecting the strengthening girders for these two bridges, and the consulting engineers adopted the same principle and design of truss as employed in case of Chambal Bridge. In the case of 60 ft. clear span at Anas, the existing girders were removed and new girders of stronger and deeper section employed, details of erection of which will be given later. So soon as material for these bridges had arrived, and the plant etc. could be removed from the Chambal Bridge the work on them was started. The situation of Anas Bridge was $3\frac{1}{2}$ miles from the nearest station viz. Anas and the configurat-:ion of ground in vicinity was such as to preclude the lay out of a girder yard in close vicinity to the bridge except at prohibitive cost, and the girder yard with workshops was laid out at Anas Station practically similar to that for Chambal Bridge, in fact the same material was employed in its construction.

The masonry piers and abutments at existing Anas Bridge, being longer the placing of necessary reinforced cement concrete bed blocks for bearings of new strengthening girders

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presented no difficulty and proceeded to completion well in advance of steelwork. The assembly, riveting up, and picking up of 100 ft. clear span girders for Anas being absolutely similar to that for Chambal Bridge, there is no need here to elaborate the detail, and with the same staff practically as had been on Chambal Bridge employed, there was no loss of time. The lead to the bridge being 3½ miles, and in order not to interfere with traffic, it was decided to place our girders the first thing in the morning, when the longest period to block the line could be obtained. The two 30 ton Loco cranes were used, and the procedure adopted was. To pick up the girder being placed from the yard after return from the bridge sling properly and then drop it down in centre of track and prop to take load off cranes ready to start off in morning marshalled in following manner Engine leading, 30 ton crane, girder, 2nd 30 ton crane and brake van. The whole moved off in this order just after 6 hours each morning and proceeded slowly to bridge, where the girder was placed by adopting exact same procedure as was used at Chambal Bridge. From the time erection was started the staff had become so expert that these 14-100 ft. clear span girders were placed at rate of one per day throughout until completion. A special staff of Khalassis were employed on bridge to fix up and service bolt, cross girders, wind bracing, and sway bracing. On completion of riveting in girder yard the necessary plant and riveting squads were transferred to bridge to carry out riveting required there, after which wooden packings were fitted, and later the Cast Iron packings.

In case of 60 ft. clear span, the new girders to replace old ones were plate girders deeper and heavier than existing ones. The author decided to rivet up this span complete in girder yard, including sway and wind bracing, and carry it as a span slung between the two 30 ton cranes.

ANAS BRIDGE.

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The slinging points were stiffened up by means of struts of 12" x 12" timber baulks suitably framed. Prior to day of placing the rivets in existing sway bracing etc. of 60 ft. span were cut out and service bolted, and the day previous the bearing plates of existing girders were removed and substituted by two short lengths each (equal to width of bearing) of 69 lbs rails laid on flat and greased. Contiguous to these were other two short pieces of similar rails on outside both ends for each girder on to which old girders would slide. The span was picked up the day before placing ready to move off in the morning, and on the day selected brought down slowly to the bridge, and suspended exactly over its final position. Bracings of existing span were then removed and two existing girders slide outwards on rail slides clear of new span. These small pieces of rails placed as substitute for bearings were removed, and new bearings placed, and new span let down on to its bearings. Both old girders were then slung up by cranes above the span, and kept suspended while track was replaced. after which the cranes with old girders slung were drawn off and taken back to the station. This work was completed b between the hours of 6.0 a.m. and 12 noon.

The accompanying photographs 1 to 4 and snapshots 1-16. shew clearly the methods employed in erection.
Plans general and detail as indicated in body of paper are similar to those attached for Chambal Bridge at Nagda.
Appendix "A" shews details of cost in carrying out work and number of rivets driven and detail cost of same for this bridge.
Erection instructions sent out by consulting engineers were similar to summary given in appendix "A" attached to paper of Chambal Bridge.

ANAS BRIDGE.

APPENDIX "A"

eting and Costs.

All rivets used on new girder work were $\frac{7}{8}$" diameter and riveting was pneumatic throughout.

The approximate number of rivets for this bridge driven in India were

(1) Rivets driven in girder yard at station - -	45,500	Nos.
(2) Rivets driven at site of bridge excluding rivets driven in replacing trough flooring displaced and hand railing -	5,900	Nos.
Total - - -	51,400	Nos.

Average number of rivets driven per squad per day - - - - - - - - - - - - - - - - -	275	Nos.
Cost of rivets driven in girder yard, including cost of labour consumable stores for compressors etc. per 100 Nos - - -	Rs. 8/12/-	
Cost of rivets driven at Bridge site including cost of labour consumable stores for compressors etc. per 100 Nos.- - -	Rs. 24/11/-	
Cost of work on Anas and Ghorakal Bridges as estimated including provision of 25% depreciation in tools and plant - - - - - - -	Rs. 228,554	
Actual cost of work as booked - - - - - - - -	Rs. 161,877	
Actual labour cost from start to completion of work in India - - - - - - - - -	Rs. 14,118	

All work was done departmentally.

Total tonnage of steelwork exclusive of packings was - - - - - - - - - - - - - - - - -	436 tons.

The Ghorakal Bridge one span of 100 ft. clear was put in hand after completion of Anas Bridge, the necessary plant and staff being transferred to Jekot which was nearest station to site viz. 5 miles from bridge. The girders were assembled and riveted on station platform, and transported in similar manner to Anas. This was a work of short duration requiring no comment. The configuration of ground at this bridge precluded assembly other than at station.

ANAS BRIDGE.

APPENDIX "A" (Contd.) 2.

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osts.
ontd.) The fabrication of steel work for Anas and Ghorakal Bridges were

Messrs Flender Akteingesellschaft Coy.,

Fur Eissen Brucken-U-Schiffleau

Belgium.

Their workmanship while on the whole good was not up to the work carried out on Mahi and Chambal Bridges.

ANAS BRIDGE

(5) New Strengthening Girder Arriving On Bridge For Fourth Span.

ANAS BRIDGE.

(2) Another View Shewing Arrival of New Girder On Bridge.

ANAS BRIDGE.

(3) New Girder Slewed Out Over Span Prior To Lowering Away

ANAS BRIDGE.

(4) View Shewing New Girder Lowered Away Into Position.

Anas Bridge.

(1) General View of Bridge Prior To Strengthening

(2) New Girder Slung Between Cranes In Girder Yard.

(3) New Girder Being Picked Up In Girder Yard.

(4) View Shewing Placing of Timber Struts Between Crane & Gird

ANAS BRIDGE

(5) Slung Girder Ready To Proceed To Bridge

(6) Arrival of Girder On Bridge.

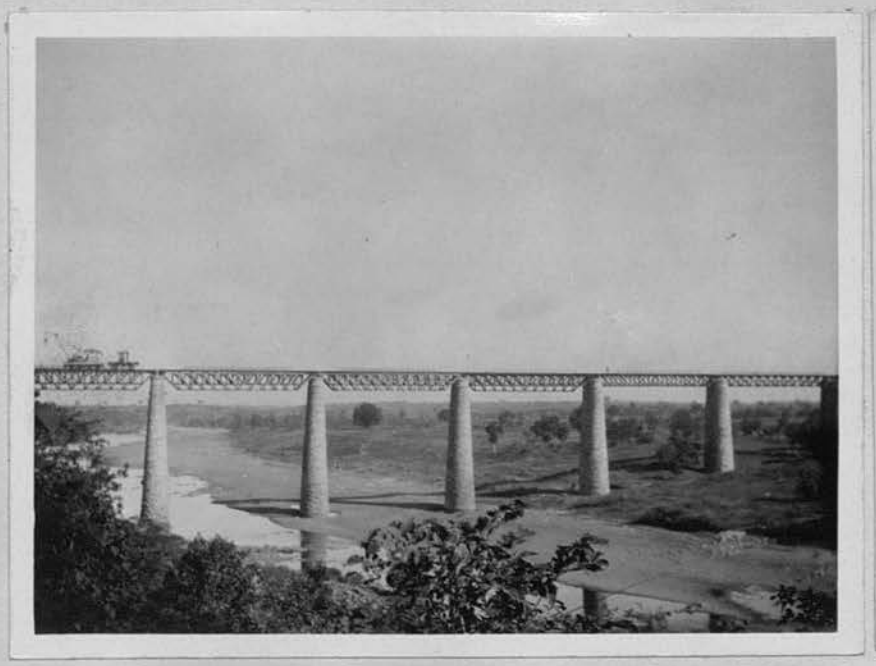
(7) Close Up View of Arrival of Girder On Particular Span.

(8) New Girder Being Lowered Away Over Side.

ANAS BRIDGE

(9) Another View of Lowering Away.

(10) Still Lowering Away

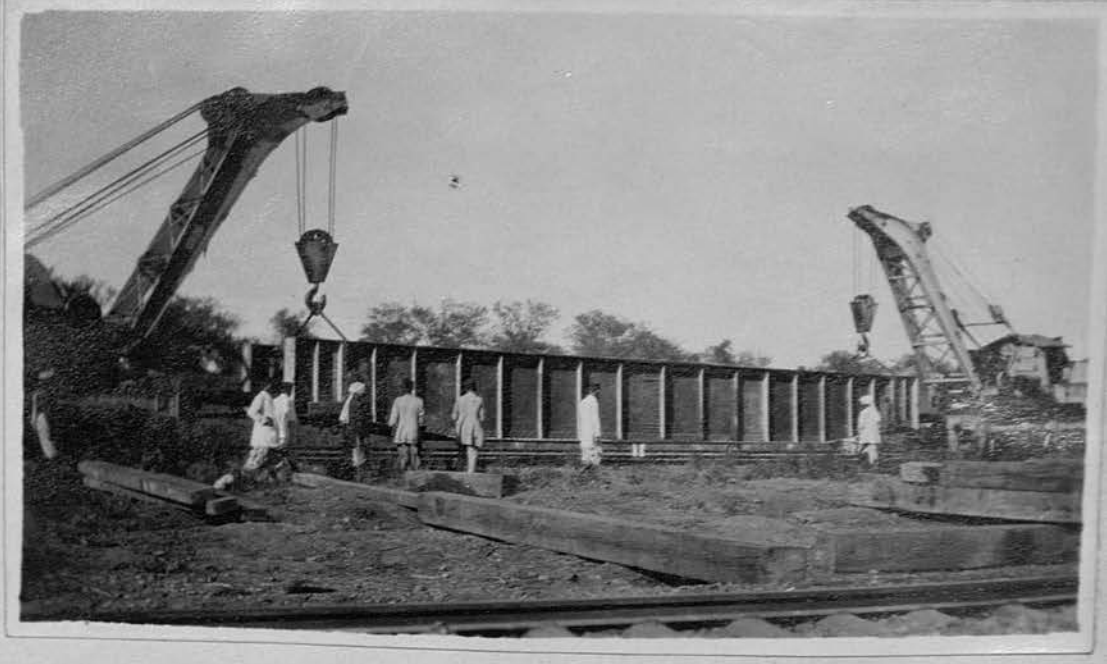


(11) Strengthening Nearing Completion.

(12) New 60'-0" Clear Span In Girder Yard.

ANAS BRIDGE.

(13) Slinging New 60'-0" Clear Span.



(14) New 60'-0" Clear Span. Slung In Girder Yard

(15) New 60'-0" Span Arriving On Bridge

(16) Strengthening Completed.